GEORGE ELLERY HALE, 1868–1938

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In the hundred years since George Ellery Hale was born in Chicago on June 29, 1868, no astronomer has made greater or more varied contributions to his science. The great telescopes and instruments he built, the institutions he founded, his discoveries in solar physics and his whole approach to astrophysics have become the foundations for progress in astronomy.

The story of Hale's life is now readily available through the new biography, *Explorer of the Universe*, by Helen Wright (1966), but it is worthwhile to sketch it briefly. From his father, William Hale, a manufacturer of elevators (including those of the Eiffel Tower), he received encouragement in technical matters. By the age of 17 he was measuring wavelengths in the Fraunhofer spectrum with a homemade spectrograph (he was to keep at these measurements all his life). He enrolled at the Massachusetts Institute of Technology, but his studies there were just a background for personal studies of solar physics. He became a volunteer assistant to E. C. Pickering, Director of the Harvard College Observatory, pursuing experiments in solar and stellar spectroscopy; his excitement over research led him to pilgrimages to the leading astronomers in the country.

Dissatisfied with the open-slit method of viewing prominences, in 1889 Hale conceived the idea of the spectroheliograph. First successful tests were made at Harvard in 1890, but the real development was carried out at the Kenwood Astrophysical Observatory, Hale's backyard solar observatory. This observatory, where many of Hale's best ideas were born, became part of the University of Chicago in 1892, with Hale's appointment as associate professor.

Hale carried out extensive research at Kenwood, exploring the sun with his new spectroheliograph and, at the same time, producing in his laboratory many of the lines he observed on the sun, thus setting an example for the work of a true *astrophysical* observatory. He discovered the calcium chromospheric network and the presence of double reversal of the H and K lines all over the sun, showing that these lines came from calcium, although he was puzzled that this element should appear to be the principal constituent of prominences. He made what were probably the first photographs of a solar flare and discovered the vortex patterns around sunspots. Hale published many of his results in articles in *Astronomy and Astrophysics*.*

* In 1892 (Hale, 1895), Hale began a journal incorporating astrophysics with astronomy, in conjunction with Payne's *Sidereal Messenger*, called *Astronomy and Astrophysics*. After 3 years he saw that a purely astrophysical journal was feasible, and the existing journal was purchased by the University of Chicago, and transformed into *The Astrophysical Journal*, which today continues as one of the great establishments which Hale left to the science of astronomy. He remained an editor until 1934.

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In 1892 Hale heard of the pair of 40-inch lens blanks which Mantois had made for the University of Southern California. U.S.C. had planned an observatory for Mount Wilson but could not carry the project through. Hale decided to get these blanks for the University of Chicago and persuaded Charles Yerkes, a streetcar magnate, to give the money for Yerkes Observatory. This transaction has been described in a novel about Yerkes, *The Titan* by Theodore Dreiser. Hale is portrayed as a far-sighted, rotund middle-aged savant whom Yerkes immediately recognized as a special person, a great builder like himself, with whom he could deal. Dreiser did not realize that Hale was only 24 years old at the time and probably an even greater promoter than Yerkes himself.

Hale personally was a solar astronomer, but because he was interested in the general progress of astronomy, he planned the Yerkes Observatory as a major night-time observatory, just as he was to spend a large fraction of his life building stellar telescopes that he would not himself use.

After he satisfied Yerkes' demands by construction of the world's greatest refractor, Hale was free to provide the observatory with good equipment for solar work. He took advantage of the great scale of the 40-inch refractor to investigate sunspot spectra. Hale lamented (HALE, 1892):

> It is safe to say that an unprejudiced student ... would be struck by the small attention given to solar investigation. It is true that in 1869 there was a great awakening of interest in the study of solar spots and prominences, due to the novel methods of spectroscopic research which had just been introduced. But, outside Italy, there are but two or three observatories which at the present time make a systematic record of solar phenomena.

So times have not changed at all.

With the completion of the Rumford Spectroheliograph in 1899, Hale was able to make better-quality pictures and, taking advantage of new photographic sensitization techniques, to study the sun in Hα for the first time.

Soon after the establishment of Yerkes Observatory, Hale began his great enterprises in California. Supported by the new Carnegie Institution, he built the Mount Wilson Solar Observatory.

We frequently forget that the great success of the California institutions was not due simply to an abundance of funds and a good site. There were more fundamental reasons why Mount Wilson succeeded. Most important was Hale's deep understanding of astronomy, physics, and engineering, which enabled him to grasp the existing problems and to solve them. Hale wrote (HALE, 1905):

> The prime object of the Solar Observatory is to apply new instruments and methods of research in a study of the physical elements of the problem of stellar evolution.

Only a profound mind could produce such a goal for a solar observatory; only such goals and programs, coupled with Hale's talents and energy, could make it successful.

Once the instruments were built, work with them was energetically pursued. The Snow telescope and spectroheliograph were in operation on Mount Wilson by the end of 1905, a year after funds for the observatory were made available. By 1908 Hale had discovered the low temperature of sunspots, their magnetic fields, the Hα vortices, and a number of lesser phenomena.

The solution of the problem of the sunspot spectrum is a most impressive example of the way Hale carried out research. Together with Walter S. Adams, he obtained a number of spectra and confirmed that the sunspots showed many new lines. He noted that the exposure for the spot (relative to the photosphere) was twice as long in the blue as in the red. Thus the sunspot must be cooler. To confirm this idea, Hale and Adams made spectra of Betelgeuse, known to be cool, with the Snow telescope and found most of the sunspot lines to be present (they actually had started this project at Yerkes). In the meantime, Hale organized Henry Gale, a young physicist, to make laboratory investigations of the excitation of many of the lines. The means were not far away: Hale never built an observatory without an impressive array of laboratory hardware – magnets, spectrographs, arcs, sparks, etc. Gale found that the sunspot lines were indeed low-excitation lines. Such co-ordinated work on the sun, the stars, and the atoms was responsible to a great degree for the success of Mount Wilson Observatory.

These multiple resources were also used in the discovery of sunspot magnetic fields. With the spectroheliograph Hale found the Hα vortices around sunspots. These suggested currents, and he understood electromagnetism sufficiently to think that the currents might produce magnetic fields. He also knew spectroscopy well enough to be able to detect them by the newly discovered Zeeman effect. The Zeeman patterns were not yet well known, but Hale had large electromagnets set up in a laboratory in Pasadena, with which Arthur S. King was able to duplicate the observed sunspot magnetic fields.

The good atmospheric conditions at Mount Wilson as well as the care Hale took in preventing seeing in the instruments led to a great advance in optical resolution. Some of Hale's 1906 spectroheliograms are quite good by modern standards. Because he and Adams could observe phenomena for many successive days, and because their good resolution enabled them to see clearly what was obscure, they achieved a new level of understanding of things which were previously poorly seen at irregular intervals. It is indeed strange that this lesson was lost. No new solar observatories were built in the West until 1942, and only recently has renewed emphasis been placed on sites with extended periods of good seeing. Solar astronomers were content to remain in cloudy places and speculate on the nature of the object of their study.

All Hale's major achievements, and those of his observatories, were made possible by the wide range of capability and vision he provided. He took the same sort of broad view in non-astronomical enterprises as well, since he was a true aristocrat in the best sense of the word. He worked many years to persuade Henry P. Huntington that his library and gallery should become an endowed research foundation rather than a dead museum; as a result, the library has become an important center for research in English literature and history. Hale's contributions to the community of Pasadena still surround us who live there. He laid out the civic center and was instrumental in founding many social and cultural institutions. The Pasadena Art Museum has finally begun building on the site he chose for it 45 years ago.

With the establishment of Mount Wilson, Hale moved into other new fields, while still continuing his own personal dynamic research program. In 1904 he organized the first meeting of the International Union for Co-operation in Solar Research, from which the International Astronomical Union developed. In 1907 he joined the Board of Trustees of the Throop Institute, a small trade school in Pasadena; within a few years he had transformed it into the nucleus of the California Institute of Technology – an institution with a new concept of the role of teaching and research within a university. Each time Hale laid out the goals in a new discipline at Caltech, he stressed fundamental understanding of the field rather than narrow professionalism. In 1916 he revitalized the U.S. National Academy of Sciences with the founding of the National Research Council and the development of the N.R.C. fellowship program.

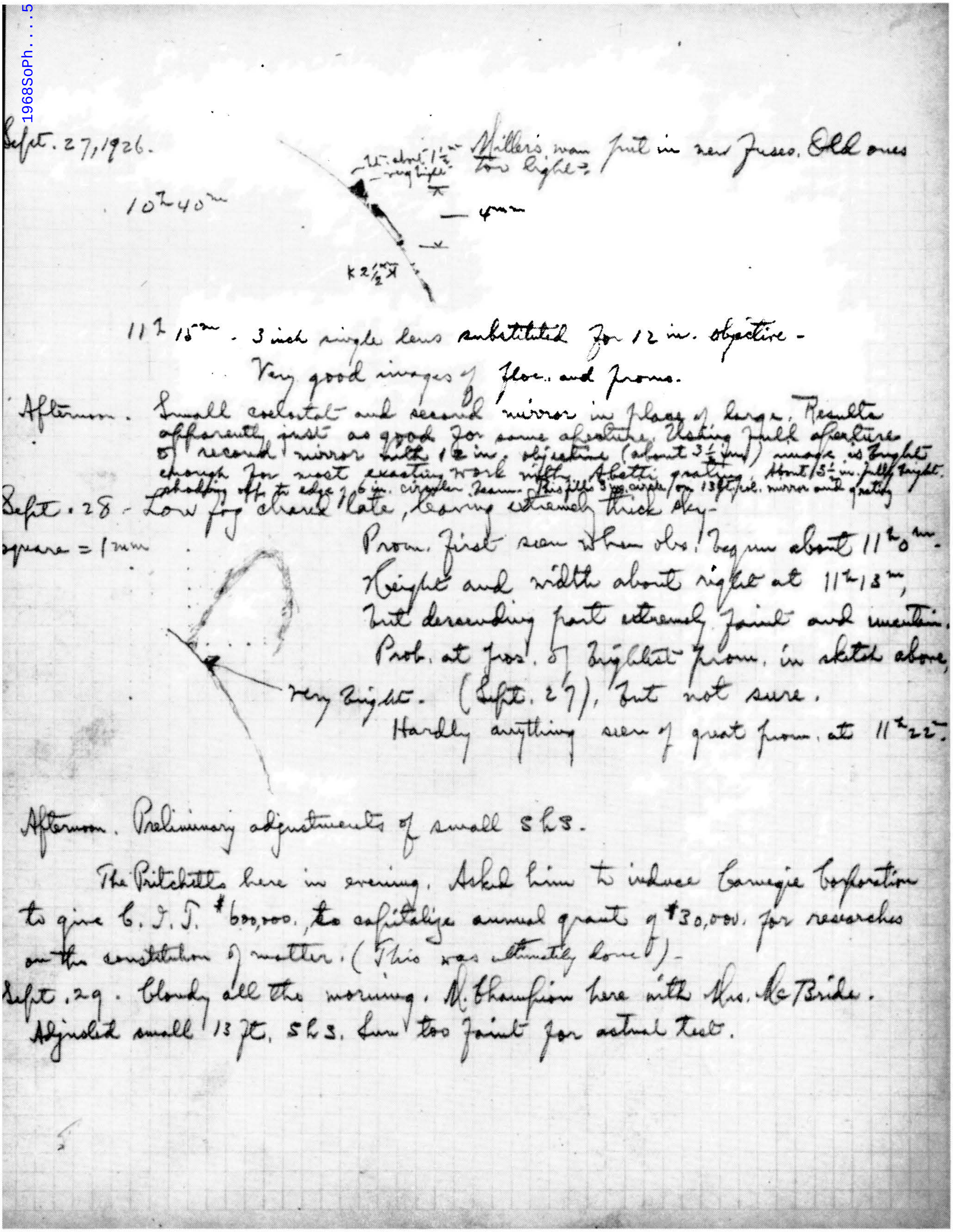
Meanwhile, work at Mount Wilson went on. In 1908 the 60-inch reflector was completed; by 1906 Hale had already placed the order for the 100-inch telescope. In 1912 the 150-foot solar tower was completed. Not many years later he began the long campaign for the construction of his greatest single achievement, the 200-inch telescope on Palomar Mountain which bears his name. At the time of his death in 1938 the telescope was funded and underway.

Hale was a solar astronomer, yet he built more stellar telescopes than any stellar astronomer. He built spectrohelioscopes and distributed them all over the world just as, many years later, the Babcock gratings advanced astronomy in many countries.

In 1922, ill and exhausted, Hale retired as director of Mount Wilson and devoted himself to research at his private observatory in Pasadena, now called the Hale Solar Laboratory and best known because Babcock and Babcock developed the magnetograph there. The average seeing in Pasadena is very good, and he accomplished a great deal.

I was fortunate enough to find two of his observing record books (now stored at the Mount Wilson Observatory) at the Hale Solar Laboratory (excerpts are shown in Figures 1 and 2). During the periods that he was in Pasadena there are records for almost every day. They give wonderful insight into Hale's feeling for the sun. He worked at developing the spectrohelioscope, at the direction of sunspot vortices, at the general solar field. In between observations, he took time with the scientific leaders of the day who appeared at his door to discuss problems of the National Academy, Caltech, the Huntington Library. When they left, he always wrote "Back to the sun…", and then perhaps detailed the results of a new lens test or spectral observation. He had great feeling for the beauty of solar phenomena. Frequently we find words like "Magnificent views of inflow to a spot…", "Beautiful vortex patterns". In our field, science and art are not far apart.

Being human, Hale made occasional mistakes. The most famous is his measurement of the general magnetic field at 50 gauss. The measurements were carefully done and repeated many times. Hale was never completely certain of the result, and



Sept. 27, 1926.

$10^h 40^m$

Ht. about $1\frac{1}{2}$ mm very bright

4 mm

K $2\frac{1}{2}$ mm

Miller's man put in new fuses. Old ones too light.

$11^h 15^m$ - 3 inch single lens substituted for 12 in. objective -
Very good images of floc. and proms.

Afternoon. Small coelostat and second mirror in place of large. Results apparently just as good for same aperture. Using full aperture of second mirror with 12 in. objective (about $3\frac{1}{2}$ ins) image is bright enough for most exacting work with Abetti grating. About $5\frac{1}{2}$ in. fully bright, shading off to edge of 6 in. circular beam. This fills 5 in. circle on 13 ft. col. mirror and grating.

Sept. 28 - Low fog cleared late, leaving extremely thick sky.

square = 1 mm

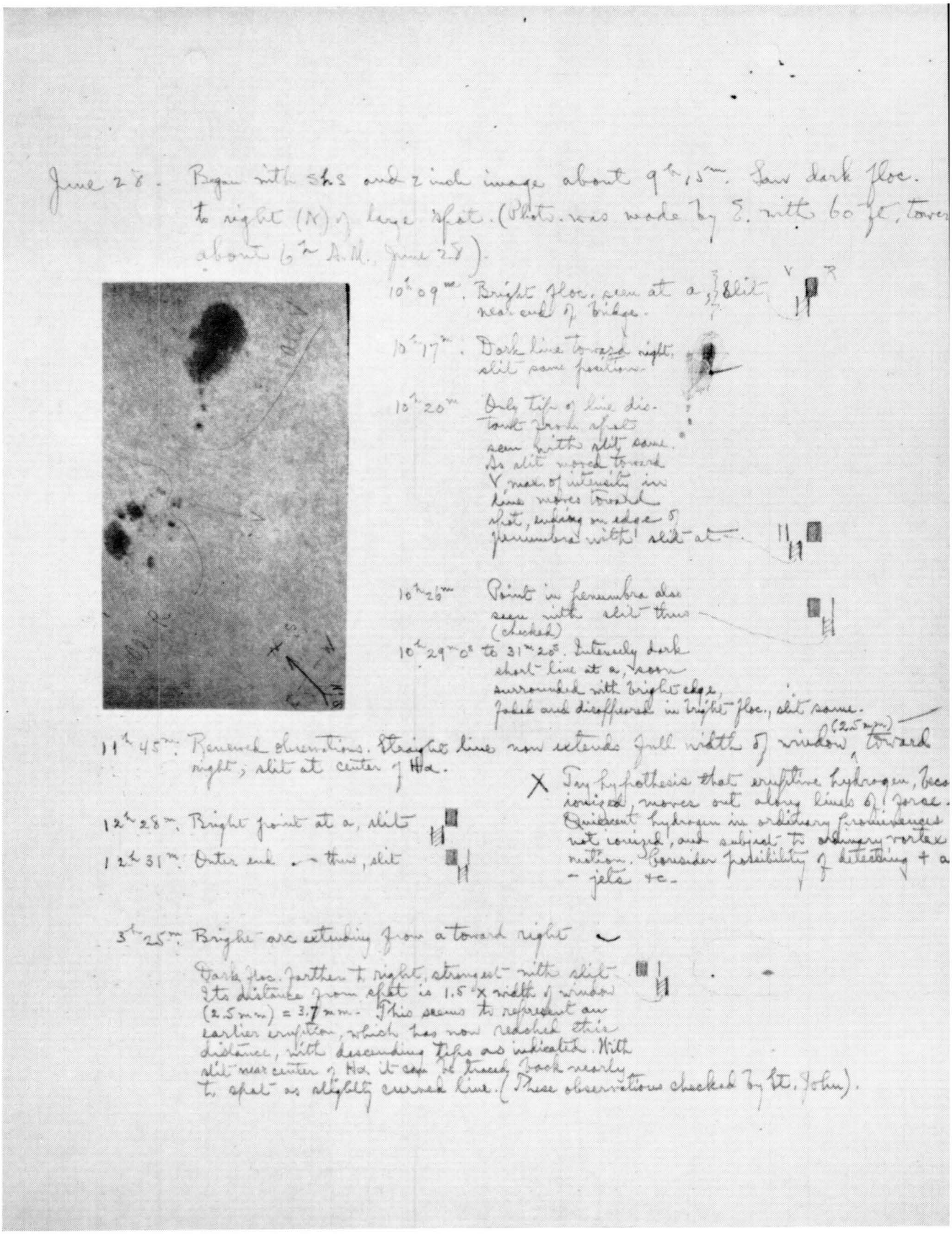
Prom. first seen when obs. began about $11^h 0^m$.
Height and width about right at $11^h 13^m$,
but descending part extremely faint and uncertain.
Prob. at pos. of brightest prom. in sketch above,
very bright. (Sept. 27), but not sure.
Hardly anything seen of great prom. at $11^h 22^m$.

Afternoon. Preliminary adjustments of small S.H.S.

The Pritchetts here in evening. Asked him to induce Carnegie Corporation to give C. I. T. \$600,000. to capitalize annual grant of \$30,000. for researches on the constitution of matter. (This was ultimately done).

Sept. 29. Cloudy all the morning. M. Champion here with Mrs. McBride.
Adjusted small 13 ft. S.H.S. Sun too faint for actual test.

Fig. 1.



June 28. Began with 5h5 and 2 inch image about $9^h, 15^m$. Saw dark floc. to right (N) of large spot. (Photo. was made by E. with 60 ft. tower about 6^h A.M., June 28).

$10^h 09^m$. Bright floc. seen at a, slit near end of bridge.

$10^h 17^m$. Dark line toward right, slit same position.

$10^h 20^m$ Only tip of line distant from spot seen with slit same. As slit moved toward V, max. of intensity in line moves toward spot, ending on edge of penumbra with slit at.

$10^h 26^m$ Point in penumbra also seen with slit thus (checked)

$10^h 29^m 0^s$ to $31^m 20^s$. Intensely dark short line at a, soon surrounded with bright edge, faded and disappeared in bright floc., slit same.

$11^h 45^m$. Renewed observations. Straight line now extends full width of window (2.5 mm), toward right; slit at center of Hα.

X Try hypothesis that eruptive hydrogen, becoming ionized, moves out along lines of force. Quiescent hydrogen in ordinary prominences not ionized, and subject to ordinary vortex motion. Consider possibility of detecting + and − jets &c.

$12^h 28^m$. Bright point at a, slit

$12^h 31^m$. Outer end thus, slit

$3^h 25^m$. Bright arc extending from a toward right

Dark floc. farther to right, strongest with slit. Its distance from spot is 1.5 × width of window (2.5 mm) = 3.7 mm. This seems to represent an earlier eruption, which has now reached this distance, with descending tips as indicated. With slit near center of Hα it can be traced back nearly to spot as slightly curved line. (These observations checked by St. John).

Fig. 2.

his final conclusion that there was a large polar field certainly stimulated research in this direction in later years.

Although far ahead of his contemporaries, Hale even made a few mistakes in instruments. The 75-foot pit spectrograph at the Hale Laboratory is a single frame designed to rotate as an enormous unit, but all the beams are neatly sawed off at the bottom because of the oscillation set up by rotation of the system. He became over-enthusiastic about folded-mirror systems like the Hale Laboratory and the 36-inch coelostat system at the Robinson Astrophysical Laboratory at Caltech in Pasadena. These have long air paths as well as sizeable off-axis aberrations, and the seeing is worse than in his earlier refractor systems in the Mount Wilson tower telescopes. The Robinson coelostat is mounted in an independent tower which shakes enough, so it has to be tied back to the building. But a large fraction of his instruments continue to operate in their original form to this day.

To consider the significance of the work of George Ellery Hale we simply need to ask ourselves: 'Where would we be today in astronomy had he not lived?' Perhaps we would just be beginning to appreciate the significance of magnetic fields in the sun and stars. The law of sunspot polarities might be a recent discovery. It is possible that the first 100-inch telescope would only now be under development. Certainly the concept of laboratory astrophysics would be a recent innovation.

Each of the great steps Hale took involved something that no one else even thought to try. To be sure, the Yerkes Observatory was to some extent a copy of the Lick 36-inch refractor, but the great solar and stellar telescopes he built in California were far beyond the most daring ideas of his time. Some have attributed Hale's accomplishments to the fact that he had some personal wealth and access to the rich, from whom he developed strong support. In actual fact, his dealings with millionaires were long, laborious, and frustrating; there have been many equally well-funded projects that have produced few concrete results.

Hale showed that science is a broad approach, not a narrow discipline, that understanding is more than mathematics and that, if difficulties or challenges exist, we do better to solve them than to bemoan them. Astronomy is a single science and the success of one astronomer is the success of all. More important, the failure of one is the failure of all. In his hundredth year, Hale's greatest monument is the achievement of astronomers all over the world who have profited from his works and built on them for deeper understanding of the universe.

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